Sugarcane Response to Mill Mud, Fertilizer, and Soybean Nutrient Sources on a Sandy Soil

Robert A. Gilbert,* Dolen R. Morris, Curtis R. Rainbolt, James M. McCray, Raul E. Perdomo, Barney Eiland, Gerard Powell, and German Montes

ABSTRACT

Improving soil organic matter and soil fertility are important factors in the sustainability of sugarcane (*Saccharum* spp.) production. A 3-yr field trial was established in 2004 on a sandy Alfisol in Florida to compare the effect of organic and inorganic nutrient sources on sugarcane production. The three nutrient sources were (i) mill mud (filter cake, cachaza), (ii) local standard fertilizer, and (iii) soybean cropping system before sugarcane. Soybean green manure increased sucrose yield (TSH, t sucrose ha^{-1}) 20% in plant cane, however when aboveground biomass was removed soybean rotation did not improve sugarcane yields. Fertilization did not increase yields if mill mud was added to plant cane. Soybean green manure did not improve sugarcane ratoon crop yields, and there were no significant interactions in the ratoon crops. The application of mill mud resulted in a 49% TSH increase in first ratoon and a 167% increase in second ratoon whereas inorganic fertilizer application increased TSH by 31 and 49% in first and second ratoon, respectively. Over the 3-yr crop cycle, addition of mill mud alone led to an increase of 4.1 TSH compared with inorganic fertilizer alone, whereas soybean green manure alone produced 2.6 TSH less than fertilizer. However, combinations of nutrient sources with mill mud had additive effects in the ratoon crops. Our results indicate that mill mud was more effective than soybean green manure or local standard fertilizer practices in increasing sugarcane yields on sand. However, growers should fertilize ratoon crops when mill mud has been applied to achieve maximum sugarcane yields.

Sugarcane growers in the United States generally rely on inorganic fertilizers to improve yields. In Florida, 78% of sugarcane acreage is on organic soils (Histosols) with high fertility, and 22% (35,000 ha) is on sandy soils (Entisols, Alfisols, and Spodosols) very low in organic matter (Glaz, 2006). However, the proportion of sugarcane grown on sandy soils has recently increased and there is grower interest in sugarcane expansion on mineral soils for both sucrose and bioenergy production. Indeed, as interest in sugarcane for bioenergy increases worldwide, there will be increased pressure to expand on marginal lands with low organic matter content. Standard fertilization practices on sandy soils in Florida involve splitting recommended rates into 3 to 4 applications (Anderson, 1989); positive yield responses with up to 13 applications have been recorded (Obreza et al., 1998). With increasing fuel and fertilizer prices, however, such a large number of applications is not profitable. Sugarcane growers in Florida and elsewhere are interested in examining nutrient management strategies involving organic fertility sources to reduce their fertilizer costs.

R.A. Gilbert, C.R. Rainbolt, and J.M. McCray, Univ. of Florida, EREC, 3200 E. Palm Beach Rd., Belle Glade, FL, 33430; D.R. Morris (deceased), USDA-ARS, Sugarcane Field Station, 12990 US Hwy. 441, Canal Point, FL 33438; R.E. Perdomo, B. Eiland, G. Powell, and G. Montes, Florida Crystals Corp., P.O. Box 86, South Bay, FL 33493. Received 18 July 2007. *Corresponding author (ragilber@ufl.edu).

Published in Agron. J. 100:845–854 (2008).
doi:10.2134/agronj2007.0247

Increasing soil organic matter on sandy soils has many benefits, such as increasing soil cation exchange capacity and nutrient cycling, water-holding capacity, and erosion control. Organic nutrient sources available to sugarcane growers include leguminous green manures and sugarcane mill mud (aka filter cake, press mud, and cachaza). The use of green manure technologies in sugarcane is not new. Arceneaux et al. (1932) examined several legume species for green manuring sugarcane in Louisiana and reported the greatest biomass and N contribution from Biloxi soybean (*Glycine max* L. Merr.), *Crotalaria juncea*, and *Cajanus indicus*. Arceneaux (1943) subsequently compared soybean green manure, soybean forage with biomass removed, and soybean forage with fertilizer added. The soybean forage and fertilizer treatment resulted in significantly higher yields than the soybean green manure treatment, and the author indicated that the traditional practice of green manuring in Louisiana needed to be re-examined. He did note, however, that the long lag time between soybean incorporation (August) and sugarcane planting (November) in Louisiana likely led to significant N losses in the green manure system.

More recent work on green manure crops and legume rotations has been reported primarily from Asia and Australia. In particular, there has been concern in Australia with sugarcane yield decline and there have been recent attempts to include legumes in the sugarcane crop rotation to improve crop productivity and soil health. Yield benefits from green manures to subsequent sugarcane crops have varied depending on legume growth, biological nitrogen fixation, and soil type, but have generally ranged from 0 to 25%. For example, Garside and

Abbreviations: C, previous cropping system; DAP, d after planting; IPAR, incident photosynthetically active radiation; KST, sucrose concentration; LAI, leaf area index; TCH, biomass yield; TPAR, transmitted photosynthetically active radiation; TSH, sucrose yield.

Bell (2001), summarizing the results of 6 yr of legume rotation experiments with sugarcane in Australia, reported cane yield improvements of 15 to 25% compared with continuous cane systems. Yadav (1995) reported significantly lower yields in a *Sesbania* aculeata–sugarcane rotation than a rice–sugarcane rotation in India, and de Resende et al. (2003) reported nonsignificant sugarcane yield increases following four green manure legumes on a sandy soil in Brazil. However, Yadav and Verma (1995) noted a 10% sugarcane biomass yield increase in a cowpea (*Vigna unguiculata*)–sugarcane rotation compared with a rice (*Oryza sativa*)–sugarcane rotation in India. The cowpea rotation also resulted in higher soil organic matter and total N throughout the sugarcane crop cycle. Bokhtiar et al. (2003) reported sugarcane yield increases of 2 to 26% following *Crotalaria juncea* and *Sesbania aculeata* green manure crops in Bangladesh.

Biological N fixation levels and N contributions from legumes influence subsequent crop performance. Garside et al. (1997) compared rotation treatments of bare fallow, cowpea, mungbean (*Vigna radiata*), peanuts, and soybeans and reported N contributions ranging from 50 kg ha^{-1} for cowpea to 310 kg ha^{-1} for soybean. Sugarcane yield response was commensurate to N contributed by the fallow crop, with no N fertilizer required in sugarcane following soybeans. Bell et al. (1998) reported plant cane yield benefits of 14% following a summer legume rotation crop of peanuts (*Arachis hypogaea* L.) or soybeans. Garside et al. (1999) also reported significant sugarcane yield responses following pasture, bare fallow, and legume rotations.

Legume rotation benefits for sugarcane may vary depending on residue management. Noble and Garside (2000) recommended a reduced traffic strategy in soybean–sugarcane rotations to retain legume residue on the soil surface, which would improve synchrony of cane nutrient uptake with legume residue mineralization. Garside and Berthelsen (2004) compared legume residue management systems and reported equivalent sugarcane yield response whether soybean residue was incorporated, left on the soil surface, or left standing. In a subsequent study, Garside et al. (2006) reported a 27% sugarcane yield increase following soybeans in Australia. Wiedenfeld (1998) compared crop rotation effects and N fertilizer rates on sugarcane yields in Texas. Sugarcane plant cane yield was affected primarily by rotational crops, whereas second ratoon yield was affected primarily by N fertilizer rate.

Mill mud, a byproduct of sugarcane milling, consists primarily of ground sugarcane leaf and stalk material, soil, and lime added in the clarification process. Mill mud contains high concentrations of N, P, and Ca. The exact nutrient concentration of mill mud varies due to differences in sugarcane variety, soil type, and mill performance. Samuels and Landrau (1956) reviewed mill mud practices in Puerto Rico, and reported that application rates up to 224 t ha^{-1} were common. Mill mud is often applied at high rates near the sugar mill as transportation costs are high, particularly for fresh material with high moisture content (Qureshi et al., 2000). Samuels and Landrau (1956) reported that application of mill mud at rates up to 134 t ha^{-1} did not increase sugarcane yields. However, this study did not include mill mud treatments without fertilizer application.

The benefits of mill mud application will vary with soil type and fertilizer use. In a review of 26 mill mud trials in South Africa, Alexander (1972) concluded that filter cake application would be most beneficial in soils with low available P. Moberly and Meyer (1978) reported that sugarcane yield response to mill mud varied with soil type in South Africa and also recommended application in soils with low P status. Roth (1971) reported a 17% average yield increase in plant cane when mill mud was furrow-applied or broadcast at rates of 67 to 180 t ha^{-1} in South Africa. Arreola-Enriquez et al. (2004) reported a significant sugarcane yield increase following application of 10 t ha^{-1} mill mud compared with inorganic fertilizer application in Mexico. Yaduvanshi and Yadav (1990) reported that mill mud application of 30 t ha^{-1} increased sugarcane biomass yield 13%, but combining mill mud and N fertilizer increased biomass yields 38% on a clay loam soil in India.

In addition to yield benefits, mill mud application has noted effects on soil health. Prasad (1974) noted that mill mud application increased soil pH, P, N, Ca, Mg, Mn, and Zn, although the N increase was not recorded until 4 mo after application. Kumar et al. (1985) found that mill mud application increased water retention and available water in a Lucas fine sand in Australia. Roth (1971) noted that mill mud application increased soil aggregate stability and decreased *Pythium* root disease microorganism populations.

While there have been numerous studies examining the effect of green manure or mill mud on sugarcane, to our knowledge there are only two published studies including green manure, mill mud, and fertilizer (Bokhtiar and Sakurai, 2005a, 2005b). Comparisons of multiple organic and inorganic sources are useful as they provide growers a direct comparison of a range of nutrient management options that can improve sugarcane yields. Increasing nutrient management options are particularly important in an economic climate of increasing fertilizer prices. Bokhtiar and Sakurai (2005a, 2005b) found increases in sugarcane leaf area index (LAI) and yield when green manure or mill mud was combined with fertilizer in Bangladesh and postulated a 25% fertilizer reduction was possible when mill mud was added at 15 t ha^{-1}. However, these studies did not include green manure or mill mud treatments without fertilizer, so the effect of organic amendments alone cannot be compared with fertilizer in these studies.

The objective of our experiment was to compare the effect of three nutrient sources, alone or in combination, on sugarcane growth and yield throughout the crop cycle (plant cane, first ratoon, and second ratoon crops). The nutrient sources were (i) mill mud (none and 224 t ha^{-1}), (ii) inorganic fertilizer (none or recommended rates), and (iii) previous cropping system (soybean as green manure with biomass incorporated, soybean as forage with biomass removed, and weedy fallow). Sugarcane growth and yield response were monitored to determine yield trends over the entire crop cycle for all 12 nutrient management combinations.

MATERIALS AND METHODS

Experimental Design

The experiment was implemented on a Holopaw sand soil (loamy, silicieous, active, hyperthermic Grossarenic Endoaqualfs) on-farm in the Everglades Agricultural Area in South Florida (26°48′ N, 80°25′ W). Before starting the experiment, the soil average cation exchange capacity was 2.6 meq 100 gm^{-1}, pH was 5.0, and organic matter was 2.4%. The experimental design was a 2 × 2 × 3 factorial in a split-split plot arrangement in a randomized complete block design with four replications. The main plot factor was ± mill mud, the subplot factor was ± fertilizer, and the sub-subplot factor was previous cropping system. Cropping system treatments consisted of either (i) soybean grown for green manure with all aboveground biomass incorporated, (ii) soybean grown for forage with all aboveground biomass removed, or (iii) weedy fallow. Soybean cultivar Hinson was planted in green manure and forage plots at the rate of 56 kg ha^{-1} with 15-cm between-row spacing on 6 June 2003. Soybean seed was treated with 42-S Thiram (tetramethylthiuram disulfide) fungicide (Bayer CropScience, Research Triangle Park, NC)[1] at a rate of 109 mL ha^{-1} (per 56 kg seed) and inoculated with Nitragin (EMD Crop Bioscience, Milwaukee, WI) at the rate of 95 g/22.5 kg. On 27 Aug. 2003, diflubenzuron (1-(4-chlorophenyl)-3-(2,6-difluorobenzoyl) urea) was applied at the rate of 0.14 kg ha^{-1} to control grasshoppers. On 3 Oct. 2003, all soybean plots were cut at ground level and biomass removed manually from the forage plots, while the soybean biomass was disked in on the green manure plots. On 19 Nov. 2003, mill mud at the rate of 224 t ha^{-1} was applied to the + mill mud plots. The entire field was disked on 21 Nov. 2003, furrows were made, and basal fertilizer rate applied to the +F plots. Each sub-subplot planted to sugarcane was eight rows wide and 13.5 m long with 1.5-m between-row spacing. Sugarcane cultivar CP 78–1628 was planted vegetatively in all plots on 25 Nov. 2003 by placing two sugarcane stalks side by side in the furrows and chopping them into billet lengths of approximately 60 cm before closing the furrows. The plant cane crop was harvested mechanically on 22 Nov. 2004. The resultant first ratoon regrowth was harvested on 19 Jan. 2006, and the second ratoon crop was harvested on 23 Oct. 2006.

Table 1. Application date, timing, and rate of nutrient addition from mill mud (applied at 224 t ha^{-1}), soybean green manure (applied at 9600 kg ha^{-1}), or inorganic fertilizer applied at recommended rates to sugarcane grown on a sandy soil in Florida. Nutrient levels represent total available N, P, K, Ca, and Mg.

Treatment	Crop†	Date	N	P	K	Ca	Mg
			kg ha^{-1}				
Mill mud‡	PC	11/19/03	77	691	328	6290	455
Green manure	PC	10/3/03	252	N/A	40	194	64
Fertilizer	PC	11/24/03	62	25	121	0	8
		5/25/04	56	0	139	0	0
		8/2/04	45	0	0	0	0
	1R	2/1/05	67	25	93	0	0
		4/11/05	62	27	130	0	9
		5/18/05	90	0	139	0	0
		5/25/05	67	0	104	0	4
	2R	2/1/06	56	20	93	0	0
		6/10/06	78	0	139	0	0
		8/1/06	56	0	0	0	0
Fertilizer 3-yr total			639	97	958	0	21

† PC = plant cane; 1R = first ratoon; 2R = second ratoon.

‡ Mill mud was applied with a C:N ratio of 23:1, adding a total of 35 t ha^{-1} C and 1.5 t ha^{-1} total N in both organic and inorganic forms.

Nutrient Additions

Table 1 summarizes the timing and amount of N, P, K, Ca, and Mg added to sugarcane via mill mud, fertilizer, or green manure treatments during the 3-yr study. The mill mud was aged for 6 to 12 mo and applied to + mill mud plots at the rate of 224 t ha^{-1} on 19 Nov. 2003. Moisture content of the applied mill mud was 54%. Mill mud total available N was determined by dry combustion (Kowalenko, 2001), available P and K by Mehlich 1 extraction (Jones, 2001), and total Ca and Mg by microwave digestion using nitric acid (Environmental Protection Agency, 1994, 1996). The C:N ratio of mill mud applied was 23:1, and total N and total C added in this treatment were 1.5 and 35 t ha^{-1}, respectively. Before soybean biomass incorporation on 3 Oct. 2003, total plot fresh weights were determined in the field and ~1-kg subsamples were weighed fresh and removed for nutrient analysis. Each sample was dried at 60°C to constant weight to determine soybean dry matter addition per plot, which averaged 9600 kg ha^{-1} (± SE 352 kg ha^{-1}). Soybean plant samples were then ground in a Wiley mill with a 1-mm screen and processed for nutrient concentration. All ground samples were dried overnight at 65°C before weighing for digestions. Total N was determined by micro-Kjeldahl digestion on an aluminum digestion block and analysis with a flow analyzer (Lachat Instruments, 2003). In the determination of total Kjeldahl N, leaf N is converted to the ammonium cation in the digestion and ammonium is converted to ammonia and determined colorimetrically with the flow analysis instrument. Plant samples were also digested with nitric acid (2 h, 150°C) followed by hydrogen peroxide (1 h, 150°C) on an aluminum digestion block. Total P was determined by nitric acid and hydrogen peroxide digestion and analysis with the phosphomolybdate blue method (Murphy and Riley, 1962). Plant K, Ca, Mg, Fe, Mn, Zn, and Cu concentrations were determined by the same digestion using atomic absorption spectrophotometry. Fertilizer was applied at standard recommended rates for Florida sugarcane production on sandy soils (Rice et al., 2006). Fertilizer was applied 3 to 4 times annually to +F plots (Table 1). Basal fertilizer application on 24 Nov. 2003 was applied directly in the open sugarcane furrows before planting. All subsequent fertilizer applications were broadcast onto the soil surface.

Leaf Area Index

Sugarcane LAI was measured at approximately monthly intervals during the spring and summer of each year. The LAI measurements in the plant cane crop were performed on 12 Mar. (107 d after planting [DAP]), 22 Apr. (148 DAP), 17 May (174 DAP), 24 Jun. (211 DAP), 28 July (241 DAP), and 23 Aug. (274 DAP) 2004. The LAI measurements in the first ratoon crop were performed on 10 Mar. (108 d after plant cane harvest), 5 Apr. (139), 13 June (204), 6 July (227), and 3 Aug. (255) 2005. The LAI measurements in the second ratoon crop were performed on 28 Mar. (68 d after first ratoon harvest), 25 Apr. (96), 9 May (109), 9 June (140), 10 July (171), 18 Aug. (210), and 15 Sept. (238) 2006. Leaf area was measured nondestructively using a SunScan Canopy Analysis System (Dynamax Inc., Houston, TX). This system uses a 1.0-m wand placed beneath the crop canopy to measure transmitted photosynthetically active radiation (TPAR); an unshaded beam fraction sensor is placed outside the plots to measure incident

[1]Names of the products are included for the benefit of the reader and do not imply endorsement or preferential treatment by the University of Florida or USDA.

photosynthetically active radiation (IPAR). The two sensors are connected with a cable and simultaneous readings of TPAR and IPAR are taken, with the difference used to calculate LAI. In a comparison of nondestructive LAI measurement systems, SunScan recorded measurements of LAI similar to AccuPar and LAI-2000 (Wilhelm et al., 2000).

As the SunScan wand is 1.0 m and between-row sugarcane spacing is 1.5 m, it was necessary to take two measurements diagonally across the sugarcane row, spanning from midpoint to midpoint, and average these readings to obtain one LAI measurement. This procedure was repeated twice per plot to obtain two measurements of LAI, which were then averaged for each plot. All measurements were performed between 10:00 and 14:00.

Leaf Nutrient Concentration

Leaf nutrient concentration samples were taken from the plant cane crop on 17 May 2004, the first ratoon crop on 27 May 2005, and the second ratoon crop on 21 June 2006. Thirty top visible dewlap leaves were harvested at random from the middle six rows of each plot. Leaf midribs were separated from leaf blades and discarded before washing the blades in deionized water and drying at 60°C. The dried leaf material was ground to pass a 1-mm screen in a stainless steel Wiley mill. All ground samples were dried overnight at 65°C before weighing for digestions. Total leaf N was determined by micro-Kjeldahl digestion on an aluminum digestion block and analysis with a flow analyzer. Leaf samples were also digested with nitric acid (2 h, 150°C) followed by hydrogen peroxide (1 h, 150°C) on an aluminum digestion block. Total P was determined by nitric acid and hydrogen peroxide digestion and analysis with the phosphomolybdate blue method (Murphy and Riley, 1962). Leaf K, Ca, Mg, Fe, Mn, Zn, and Cu concentrations were determined by the same digestion using atomic absorption spectrophotometry.

Yield Measurements

Millable stalks from the middle six rows in each plot were counted in August of 2004 (plant cane), 2005 (first ratoon), and 2006 (second ratoon). Yield measurements were performed on 22 Nov. 2004 (plant cane), 11 Jan. 2006 (first ratoon), and 23 Oct. 2006 (second ratoon). A 40-stalk yield random sample was used to calculate cane production. Plant fresh weights were used to determine individual stalk weight (kg stalk^{-1}), and biomass yield (TCH, t cane ha^{-1}) was calculated as the product of stalk number and stalk weight. To determine sucrose concentration (KST, kg sucrose t^{-1}), a 10-stalk harvest random sample was milled and the crusher juice analyzed for Brix and pol. Brix, which is a measure of percent soluble solids, was measured using a refractometer that automatically corrected for temperature. Pol, which is a unitless measure of the polarization of the sugar solution, was measured using a saccharimeter. The KST was determined according to the theoretical recoverable sugar method (Glaz et al., 2002). The TSH (t sucrose ha^{-1}) was calculated as the product of TCH and KST (divided by 1000 to convert kg sucrose to metric tons).

Statistical Analyses

Analyses of variance for all measurements were performed using the PROC GLM procedure for a split-split plot arrangement in a randomized complete block design in SAS, with mill mud treatment as the main plot, fertilizer as the subplot, and cropping system the sub-subplot (Littell et al., 2002). Least significant differences ($P < 0.05$) were determined for all significant treatment effects. In addition, least squares means statements were used to determine probabilities of significant differences in preplanned pairwise contrasts between each treatment and the commercial fertilizer rate control, as well as preplanned contrasts of high vs. no organic matter additions and mill mud vs. soybean additions.

RESULTS

For sugarcane crop yield and LAI data, analyses of combined crops revealed significant interactions involving crops, therefore each crop was analyzed separately. For the LAI data, additional analyses of multiple sample dates within a crop were performed using the repeated statement, and results reported separately by sample date due to significant interactions involving sample dates.

Plant Cane Crop

LAI differences among treatments varied by sample date. Significant differences in plant cane LAI were noted beginning 175 DAP (Fig. 1A). By the last measurement date at 274

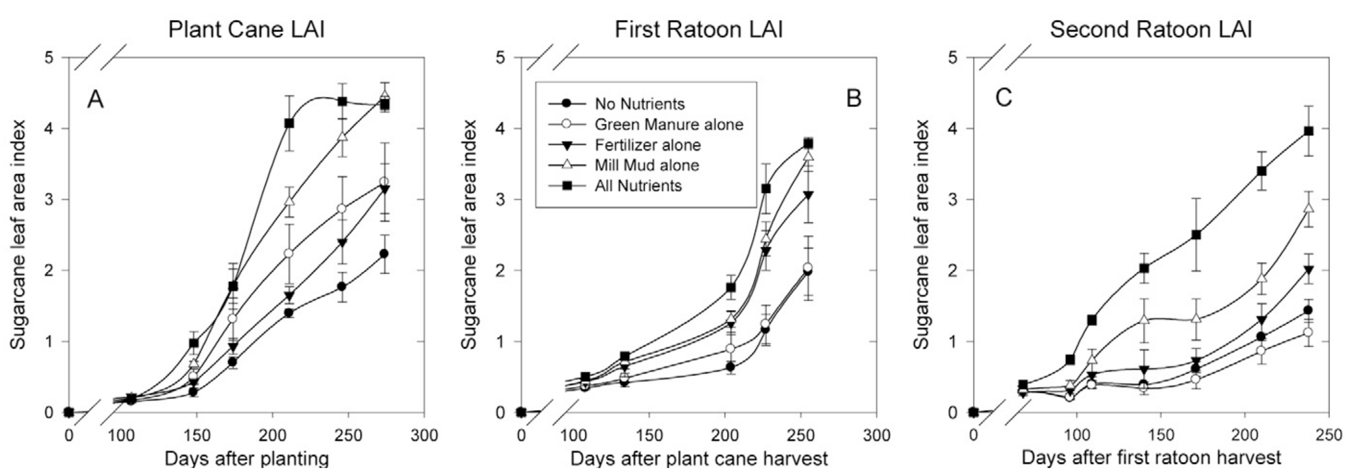

Fig. 1. Sugarcane leaf area index (LAI) in the (A) plant cane, (B) first ratoon, and (C) second ratoon crops for five nutrient management treatments.

Table 2. Sugarcane leaf N, P, K, Fe, and Mn nutrient concentrations in the plant cane, first ratoon and second ratoon crops.

Treatment†	N	P	K	Fe	Mn
	g kg^{-1}			mg kg^{-1}	
Plant cane					
Mill mud					
Yes	27.7 a‡	2.7 a	15.2 a	57.7 a	14.0 a
No	24.1 b	2.5 b	10.3 b	51.9 b	9.5 b
Fertilizer					
Yes	26.6 a	2.6	13.4 a	54.6	13.3 a
No	25.3 b	2.6	12.2 b	55.0	10.2 b
Crop. sys.					
GM	27.9 a	2.6	14.4 a	56.8	13.3 a
Fallow	23.8 c	2.6	12.4 b	54.0	10.4 b
Forage	26.1 b	2.6	11.6 b	53.7	11.0 b
First ratoon					
Mill mud					
Yes	14.3	2.9 a	11.0	59.9	24.8 a
No	13.7	2.6 b	10.4	48.7	19.6 b
Fertilizer					
Yes	14.3	2.8	11.5 a	56.8	24.5 a
No	13.8	2.7	9.9 b	51.7	20.0 b
Crop. sys.					
GM	13.7	2.8	11.1	62.1	21.9
Fallow	13.9	2.6	10.6	54.7	22.1
Forage	14.5	2.8	10.4	46.1	22.6
Second ratoon					
Mill mud					
Yes	14.9 a	2.6	11.7 a	54.4 a	29.1 a
No	12.8 b	2.4	10.2 b	50.7 b	19.7 b
Fertilizer					
Yes	16.0 a	2.6	12.0 a	58.4 a	29.6 a
No	11.8 b	2.4	9.8 b	46.7 b	19.1 b
Crop. sys.					
GM	14.4	2.6	11.1	53.3	24.8
Fallow	13.8	2.5	10.8	53.5	23.4
Forage	13.6	2.4	10.9	50.9	24.9

† Nutrient management treatment: Mill mud: Yes = mill mud applied at 224 t ha^{-1}, No = no mill mud applied. Fertilizer: Yes = fertilizer applied at recommended rates (see Table 1), No = no fertilizer applied. Crop. sys., cropping system: GM = soybean green manure biomass (9600 kg ha^{-1}) incorporated, fallow = weedy fallow, forage = soybean forage crop removed.

‡ Means followed by different letters within the same crop and nutrient treatment are significantly different ($P < 0.05$).

Table 3. Analysis of variance *F* ratios and level of significance for sugarcane stalk number, stalk weight, sucrose concentration (KST), biomass yield (TCH), and sucrose yield (TSH) for nutrient treatment effects and interactions in the plant cane, first ratoon, and second ratoon crops.

Treatment	Stalk no.	Stalk wt.	KST	TCH	TSH
	stalks m^{-2}	kg stalk^{-1}	kg sucrose t^{-1}	t cane ha^{-1}	t sucrose ha^{-1}
Plant cane					
Mill mud (M)	137.00**	62.00**	6.40	106.00**	75.70**
Fertilizer (F)	1.30	8.40*	0.67	8.00*	11.40*
Crop. sys. (C)	7.60**	12.40***	0.86	13.30***	10.30***
M × F	0.38	26.60**	25.50**	24.70**	14.90**
M × C	2.80	1.60	0.34	1.70	2.30
F × C	0.41	0.18	2.15	0.05	0.10
M ×F × C	0.49	0.28	0.73	0.18	0.27
First ratoon					
Mill mud (M)	3.06	116.00**	8.40	37.30**	23.20*
Fertilizer (F)	23.10**	4.96	0.40	14.30**	14.90**
Crop. sys. (C)	0.22	2.71	0.69	0.99	0.94
M × F	1.13	2.82	1.02	0.00	0.00
M × C	0.82	0.28	0.50	0.80	0.87
F × C	1.60	0.35	1.02	1.56	1.13
M × F × C	0.01	1.08	0.80	0.82	0.37
Second ratoon					
Mill mud (M)	27.50*	141.00**	0.54	61.70**	88.40**
Fertilizer (F)	15.40**	44.20***	5.30	40.60***	28.80**
Crop. sys. (C)	5.10*	0.34	5.10*	1.80	2.60
M × F	2.50	5.10	0.14	2.20	2.70
M × C	0.39	1.40	0.27	0.08	0.03
F ×C	0.59	0.20	2.70	0.30	0.22
M × F × C	0.98	2.10	0.27	0.59	0.41

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

DAP, LAI of the mill mud and all nutrient combined treatment (4.3–4.4) was significantly greater than fertilizer or green manure only (3.2–3.3), which was significantly greater than the treatment without nutrient additions (2.3).

Addition of mill mud led to significantly greater sugarcane leaf nutrient N, P, K, Fe, and Mn concentrations in plant cane (Table 2). Addition of inorganic fertilizer also significantly increased sugarcane leaf N, K, and Mn content, but the magnitude of increase was less than that of mill mud. The addition of soybean green manure resulted in significantly higher sugarcane leaf N, K, and Mn values compared with the fallow or forage treatments in plant cane (Table 2). Leaf Ca, Mg, Zn, and Cu levels were not significantly increased by any nutrient management treatment (data not shown).

Table 3 presents analyses of variance *F* ratios and levels of significance for sugarcane yield traits in the plant cane, first ratoon, and second ratoon crops. In plant cane, both previous cropping system and application of mill mud had significant effects on sugarcane stalk number, stalk weight, TCH, and TSH. Addition of inorganic fertilizer had a significant effect on sugarcane stalk weight, TCH, and TSH. The interaction of mill mud × fertilizer application was significant on sugarcane stalk weight, TCH, and TSH. No other interaction term was significant in plant cane. With the exception of the mill mud × fertilizer effect on KST, yield trait differences due to nutrient additions were due to differences in sugarcane biomass yield rather than sucrose content.

Figure 2 presents cropping system means for significant plant cane yield traits. The addition of soybean green manure led to increases of 15% in stalk weight (Fig. 2A), 23% in TCH (Fig. 2B), and 20% in TSH yield (Fig. 2C) compared with the weedy fallow control. There were no significant differences between the weedy fallow treatment and soybean grown for forage with aboveground biomass removed, indicating no sugarcane yield benefit from decomposition of belowground soybean roots and nodules.

Since the mill mud × fertilizer interaction term was significant, these interaction means are presented in Fig. 3 rather than mill mud or fertilizer means separately. When mill mud was not applied (– mud), treatments receiving fertilizer (+ fertilizer) recorded a 52% increase in sugarcane stalk weight (Fig. 3A), a 57% increase in TCH (Fig. 3B), and a 43% increase in TSH (Fig. 3C). However, when mill mud was applied (+ mud), application of fertilizer had no effect on plant cane yield traits (Fig. 3). Application of mill mud increased plant cane TSH 84% when fertilizer was not applied and 28% when fertilizer was applied (Fig. 3C).

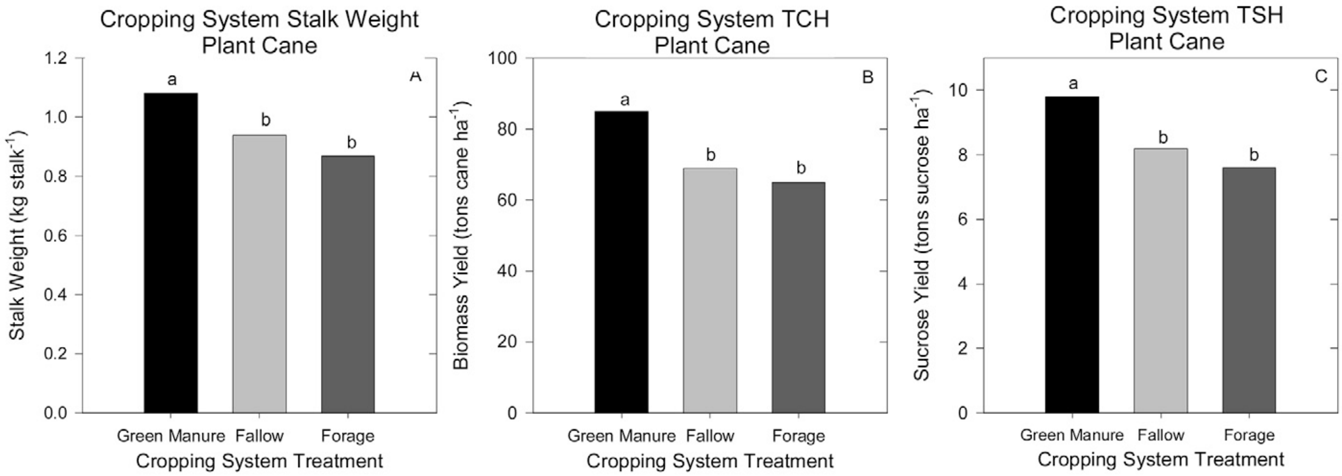

Fig. 2. Cropping system treatment means for (A) stalk weight, (B) cane yield (TCH), and (C) sucrose yield (TSH) in the plant cane crop. Different letters represent significant differences among cropping system means (P < 0.05).

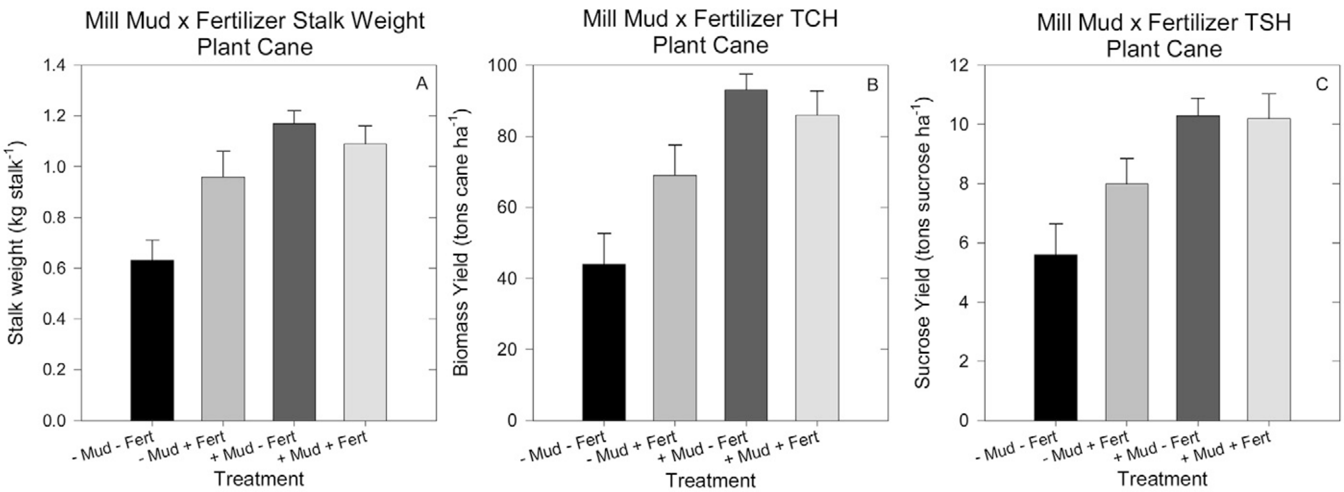

Fig. 3. Significant mill mud × fertilizer interaction means for A) stalk weight, B) cane yield (TCH), and C) sucrose yield (TSH) in the plant cane crop.

Ratoon Crops

In contrast to the plant cane crop, sugarcane recorded similar LAI values in the green manure alone and no nutrient treatments in first ratoon (Fig. 1B). The mill mud alone and all nutrient treatments again had significantly greater LAI (3.6–3.8) than the green manure and no nutrient treatments at 250 d after plant cane harvest. In the second ratoon crop, the treatment combining all nutrient additions had clearly superior LAI throughout the growing season (Fig. 1C), recording a maximum value of 4.0 compared with 2.9 for mill mud alone and 2.0 for fertilizer alone.

Sugarcane leaf N (second ratoon), P (first ratoon), K (second ratoon), Fe (second ratoon), and Mn (first and second ratoon) concentrations increased when mill mud was applied (Table 2). The addition of inorganic fertilizer led to significant increases in sugarcane leaf N (second ratoon), K (first and second ratoon), Fe (second ratoon), and Mn (first and second ratoon) in the ratoon crops. In contrast to plant cane, the addition of soybean green manure did not increase sugarcane leaf nutrient concentration in the ratoon crops.

The addition of mill mud had a significant effect on stalk weight, TCH, and TSH in first ratoon, and on stalk number, stalk weight, TCH, and TSH in second ratoon (Table 3). Unlike the plant cane crop, cropping treatment effects were not significant on sugarcane biomass or TSH in the ratoon crops (Table 3). The addition of inorganic fertilizer significantly affected sugarcane stalk number, TCH, and TSH in first ratoon and affected stalk number, stalk weight, TCH, and TSH in second ratoon. Unlike the plant cane crop, the interaction of mill mud × fertilizer was not significant in the ratoon crops, nor were any other interaction terms significant.

The addition of mill mud led to significant sugarcane yield increases in both ratoon crops, but the percent increase was greater for the second ratoon crop. Application of mill mud led to a 43% increase in sugarcane stalk weight in first ratoon and an 82% increase in second ratoon (Fig. 4A). Sugarcane TCH increased 58% in first ratoon and 167% in second ratoon in treatments in which mill mud was applied (Fig. 4B). One reason for the larger effect of mill mud on TCH in second ratoon was the significant increase in sugarcane plant population from 4.6 to 6.9 stalks m^{-2} in that crop (data not shown). Application of mill mud resulted in a 49% TSH increase in first ratoon and a 167% increase in second ratoon (Fig. 4C).

Application of inorganic fertilizers also had a significant effect on sugarcane yield traits in first and second ratoon, but the magnitude of this effect was smaller for fertilizer than mill mud. Treatments with fertilizer applied recorded 20% greater plant

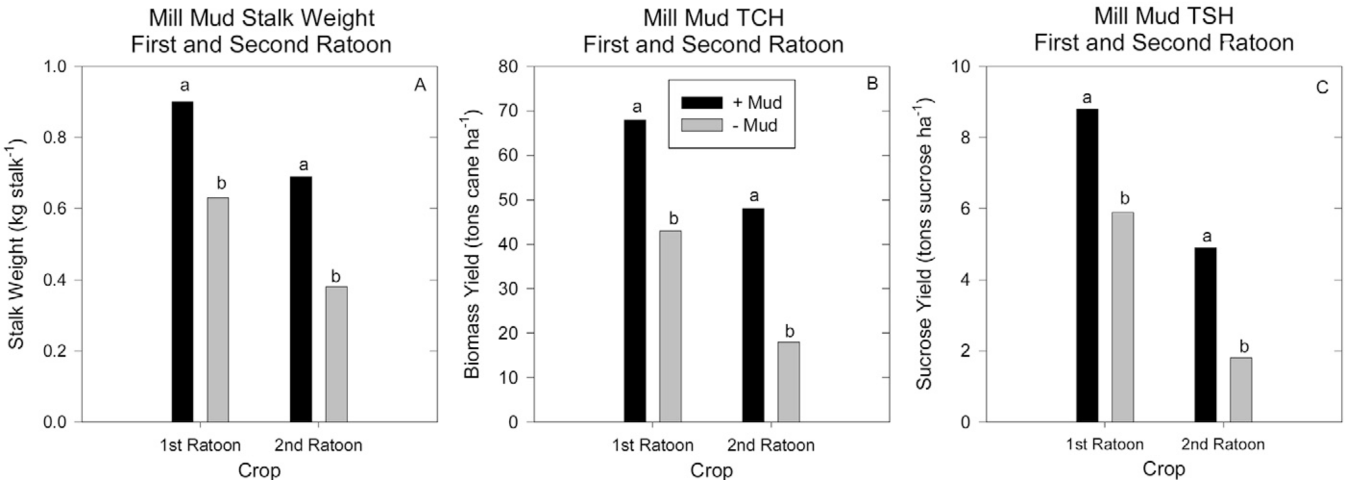

Fig. 4. Mill mud treatment means for (A) stalk weight, (B) cane yield (TCH), and (C) sucrose yield (TSH) in the first ratoon and second ratoon crops. Different letters within a crop represent significant differences between mill mud treatment means (P < 0.05).

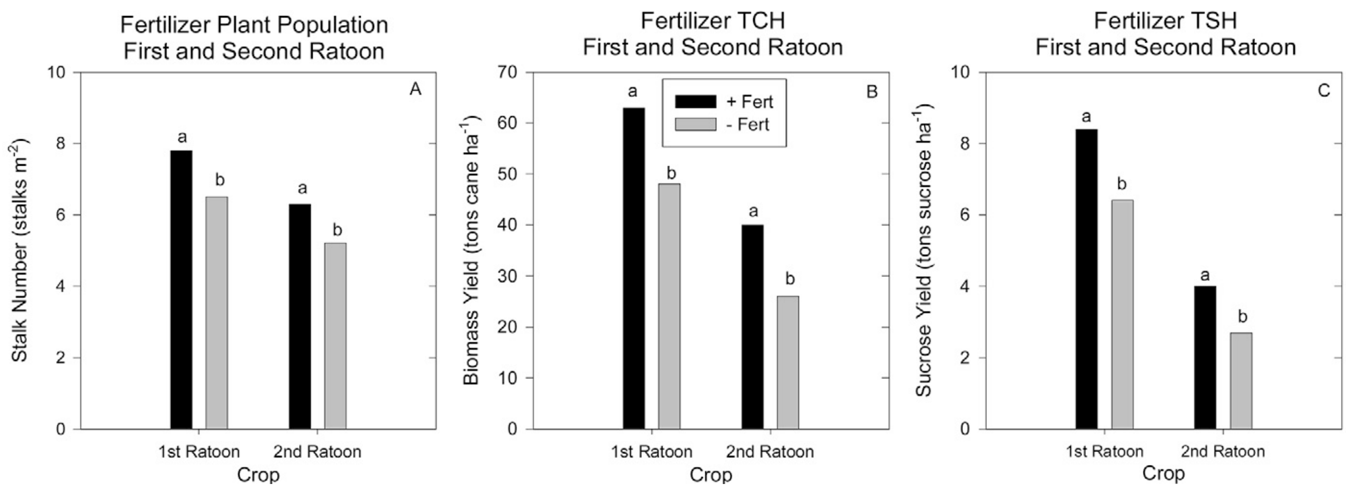

Fig. 5. Fertilizer treatment means for (A) plant population, (B) cane yield (TCH), and (C) sucrose yield (TSH) in the first ratoon and second ratoon crops. Different letters within a crop represent significant differences between fertilizer treatment means (P < 0.05).

population in first ratoon and 21% in second ratoon (Fig. 5A). Sugarcane TCH increased 31% with application of fertilizer in first ratoon and 54% in second ratoon (Fig. 5B), and TSH increased 31% in first ratoon and 48% in second ratoon with fertilizer application (Fig. 5C).

Cumulative Yields and Preplanned Contrasts

While examining main treatment effects and their interactions is informative, growers are often interested in the effect of specific management strategies compared with recommended fertilization practices. Thus we had preplanned pairwise contrasts of 11 treatments to the fertilized control. Table 4 presents TSH for all 12 treatments in the plant cane, first ratoon, and second ratoon crops as well as cumulative 3-yr yields, along with associated P values comparing each treatment to the recommended fertilizer rate control (Treatment

Table 4. Sucrose yields (TSH) and probability levels (shown in parentheses) associated with pairwise contrasts with the no mud, fertilized, fallow control treatment (Treatment 4) for all 12 nutrient management treatments on a sandy soil in Florida for the plant cane, first ratoon, and second ratoon crops, and 3-yr cumulative.

Treat. no.	Mud†	Fert‡	Crop§	Plant cane TSH	First ratoon1R TSH	Second ratoon TSH	3-yr TSH
				t sucrose ha^{-1}			
1	No	No	Fallow	4.8 (0.0016)	4.9 (0.014)	1.4 (0.158)	11.3 (0.003)
2	No	No	Forage	4.2 (0.0034)	4.7 (0.007)	1.1 (0.045)	10.0 (0.0007)
3	No	No	GM	7.7 (0.71)	5.1 (0.020)	1.5 (0.187)	14.4 (0.15)
4	No	Yes	Fallow	7.4	7.4	2.2	17.0
5	No	Yes	Forage	7.2 (0.83)	6.2 (0.186)	1.8 (0.421)	15.1 (0.29)
6	No	Yes	GM	9.6 (0.03)	7.2 (0.828)	2.6 (0.390)	19.4 (0.17)
7	Yes	No	Fallow	10.3 (0.0066)	6.9 (0.564)	4.0 (0.002)	21.1 (0.028)
8	Yes	No	Forage	9.8 (0.0184)	8.0 (0.510)	3.9 (0.003)	21.7 (0.013)
9	Yes	No	GM	10.9 (0.0012)	8.7 (0.165)	4.4 (0.0003)	24.0 (0.0005)
10	Yes	Yes	Fallow	10.3 (0.0067)	10.0 (0.008)	6.0 (<0.0001)	26.2 (<0.0001)
11	Yes	Yes	Forage	9.4 (0.0445)	9.6 (0.020)	5.3 (<0.0001)	24.4 (0.0003)
12	Yes	Yes	GM	10.9 (0.0015)	9.9 (0.009)	5.8 (<0.0001)	26.7 (<0.0001)

† Mill mud treatment: Yes = mill mud applied at 224 t ha^{-1}, No = no mill mud applied.

‡ Fertilizer treatment: Yes = fertilizer applied at recommended rates (see Table 1), No = no fertilizer applied.

§ Cropping system treatment before sugarcane planting: Fallow = weedy fallow, Forage = soybean forage crop removed, GM = soybean green manure biomass (9600 kg ha^{-1}) incorporated.

4). The application of mill mud alone (Treatment 7) produced an additional 4.1 t sucrose ha^{-1} compared with the fertilizer control over 3 yr ($P = 0.028$), whereas the addition of soybean green manure alone (Treatment 3) produced 2.6 t sucrose ha^{-1} less than the control ($P = 0.15$). The use of soybean for forage with the aboveground biomass removed (Treatment 2) and the weedy fallow treatment with no nutrients added (Treatment 1) led to significant 3-yr yield penalties of 5.7 to 7.0 t sucrose ha^{-1} compared with the fertilized control (Table 4). Conversely, combinations of nutrient sources with mill mud had additive effects in the ratoon crops, leading to highly significant 3-yr yield increases of 7.0 t sucrose ha^{-1} for mill mud + green manure (Treatment 9, $P = 0.0005$), 9.2 t sucrose ha^{-1} for mill mud + fertilizer (Treatment 10, $P < 0.0001$), and 9.7 t sucrose ha^{-1} for mill mud + fertilizer + green manure (Treatment 12, $P < 0.0001$), compared with the fertilized control.

In addition to comparison with standard fertilization practices, we had two preplanned contrasts for differing organic nutrient addition strategies. We recorded highly significant differences between no organic matter additions (Treatment 1) and high organic matter additions of mill mud + green manure (Treatment 9) of 12.7 t sucrose ha^{-1} over 3 yr ($P < 0.0001$). The addition of mill mud alone (Treatment 7) resulted in a highly significant sugarcane yield benefit compared with soybean green manure alone (Treatment 3) of 6.7 t sucrose ha^{-1} over 3 yr ($P = 0.0008$).

DISCUSSION

Our results indicate that organic nutrient amendments to a sandy soil can have significant effects on sugarcane growth and yield, but responses differed due to source and crop cycle. The 20% TSH increase we recorded in the plant cane crop due to soybean green manure application is similar to previous results using cowpea on a sandy loam soil in India (Yadav and Verma, 1995), *Crotalaria juncea* on a calcareous soil in Bangladesh (Bokhtiar et al., 2003), and soybeans in a wide variety of soils in Australia (Garside and Bell, 2001). Our results concur with Garside and Bell (2001) that a well-managed legume crop can provide a benefit equivalent to recommended fertilizer rates in the plant cane crop.

As with TSH, beneficial effects of the legume rotation on LAI were noted in the plant cane crop only. Sugarcane LAI, leaf nutrient concentrations, and yields in the first and second ratoon crops were not improved by green manuring before planting. This indicates that nutrient mineralization from above- and belowground soybean biomass was minimal during the ratoon crops. Our results indicate that sugarcane growers on sandy soils may need to fertilizer ratoon crops of sugarcane following green manure application at planting to improve TSH. Combining fertilizer and green manure produced an additional 5 t sucrose ha^{-1} (35% increase) over the 3-yr sugarcane crop cycle compared with green manure application alone.

When soybean aboveground biomass was removed for forage, there was no yield benefit to succeeding sugarcane crops. Indeed there was a trend toward slightly lower yields in forage compared with weedy fallow plots. Golden (1982) also reported a reduction in sugarcane yields following soybeans harvested for grain in Louisiana. Our results indicate that soybean nutrient mining of P, K, and other nutrients that were removed in the aboveground biomass outweighed nutrient additions from decaying soybean roots and nodules.

The highly significant mill mud × fertilizer interaction in the plant cane crop suggests that sugarcane growers do not need to add inorganic fertilizer to plant cane when high rates (224 t ha^{-1}) of mill mud are broadcast. Our study was conducted on a sandy soil low in organic matter where one would expect the benefits of fertilization to be high, so it is likely that fertilizer would not be necessary when mill mud is broadcast at high rates on other soil types with higher clay and organic matter contents. Differences in soil type are important in interpreting results from mill mud experiments. Unlike the highly significant sugarcane yield benefit with application of mill mud in our study, Samuels and Landrau (1956) concluded that mill mud had "very little residual action in the soil." However, their mill mud treatments all included inorganic fertilizer, and their experiments were performed on clayey soils. Moberley and Meyer (1978) noted a differential sugarcane yield response due to soil type in South Africa, with soils with high P-fixation capacity recording the largest yield increases when mill mud was applied.

It is important to note that mill mud from different sources and moisture contents will have differing nutrient contents. Alexander (1971), in a survey of mill mud chemical composition in South Africa, reported air-dry average values of 1.69% total N, 0.72% available P, 0.19% available K, 1.84% total Ca, and 0.37% total Mg. In contrast, our mill mud air-dry samples averaged 1.05% total N, 0.31% available P, 0.15% available K, 7.8% total Ca, and 0.50% total Mg. The most notable difference in our sample was the high Ca content, which provided a liming effect on the soil (Morris et al., 2007). The Ca content in our mill mud sample was also considerably higher than the 2.18% total Ca reported in Puerto Rico (Samuels and Landrau, 1956), however Bokhtiar and Sakuria (2005a) reported 6.6% Ca in mill mud from Bangladesh from a region with calcareous silt loams of pH = 8.0. Lime is added at variable rates to clarification processes at the mill, which increases Ca content in mill mud. There is no evidence to suggest that Florida mills add higher seasonal concentrations of lime than mills elsewhere. One possible source of increased Ca content in our mill mud is the underlying limestone bedrock in the Everglades Agricultural Area ,which releases free Ca and increases muck soil pH above neutrality.

Both mill mud and standard fertilizer application had highly significant effects on ratoon crop yields, but the magnitude of the yield increase was greater with mill mud (49% in first ratoon and 167% in second ratoon) than standard fertilizer application (31% in first ratoon and 48% in second ratoon). One reason for the magnitude of the mill mud effect may have been the large amounts of organic C added in this treatment, which have been shown to ameliorate soil nutrient and water-holding capabilities. This benefit may have been especially valuable in the sandy soil used in this study. In addition, while available N added initially was lower than the green manure and fertilizer treatment, the mill mud treatment added a large pool of organic N that would have become available via mineralization during the 3-yr crop cycle.

Our results indicate that addition of mill mud at high rates was more beneficial on a sandy soil than inorganic fertilizer, particularly for the second ratoon crop. There are two reasons that sugarcane growers may want to use high rates of mill mud. First, transport costs are high, particularly for fresh mill mud with high moisture content. Thus, mill mud is often applied at high rates near the mill (Qureshi et al., 2000). Second, growers may apply high rates in an attempt to extend the number of profitable sugarcane ratoon crops before replanting. While all treatment yields declined in second ratoon, our results indicate that mill mud application maintained sugarcane yields in ratoon crops better than inorganic fertilizer or green manure. Thus, sugarcane growers on sandy soils may want to apply mill mud at high rates to delay plow out of the crop.

Our results also indicate that cumulative 3-yr crop cycle yields of treatments receiving mill mud alone produced 4.1 t sucrose ha^{-1} (24% increase) more than the standard fertilizer rate alone and 6.7 t sucrose ha^{-1} (47% increase) more than green manure alone. Thus, the application of mill mud was more effective than green manure or fertilizer in maintaining sugarcane yields on a sandy soil. However, due to additive effects of combining nutrient sources on ratoon crop yields, maximum crop cycle yields were recorded for treatments with a combination of mill mud and green manure and/or fertilizer. These nutrient combinations resulted in an additional 2.9 to 5.6 t sucrose ha^{-1} (14–27%) over the 3-yr crop cycle when compared with mill mud addition alone. Thus, sugarcane growers on sandy soils with low organic matter may benefit from fertilization of ratoon crops when mill mud is applied. The sugarcane yield benefits from combinations of mill mud and fertilizer will have to be weighed with the economic and environmental costs of high levels of nutrient additions.

CONCLUSIONS

Our study showed that organic additions of mill mud and green manure can be effective in increasing sugarcane yields on a sandy soil. Green manure application was effective in plant cane, but not the ratoon crops. Application of mill mud at high rates rendered plant cane fertilization unnecessary and mill mud had a strong residual effect on the first and second ratoon crops. Sugarcane growers interested in reducing fertilizer inputs would benefit from mill mud application. However, additive effects of mill mud and fertilizer in the ratoon crops indicate that growers may need to combine nutrient sources to obtain maximal ratoon crop yields in sandy soils.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of Miguel Baltazar and Jairo Sanchez of EREC in data collection and processing. Names of the products are included for the benefit of the reader and do not imply endorsement or preferential treatment by the University of Florida or USDA.

REFERENCES

Alexander, K.E.F. 1971. Analyses of filter cake from South African sugar mills. Proc. S. Afr. Sugar Technol. Assoc. 45:149–151.

Alexander, K.E.F. 1972. Filter cake. S. Afr. Sugar J. 56:71–77.

Anderson, D.L. 1989. A review: Soils, nutrition, and fertility practices of the Florida sugarcane industry. Proc. Soil Crop Sci. Soc. Fla. 49:78–87.

Arceneaux, G. 1943. Does it pay to plow under soybean? Sugar Bull. 21:114–116.

Arceneaux, G., N. McKaig, Jr., and I.E. Stokes. 1932. Studies of soybeans and other green manure crops for sugarcane plantations. J. Am. Soc. Agron. 24:354–363.

Arreola-Enriquez, J., D.J. Palma-Lopez, S. Salgado-Garcia, W. Camacho-Chiu, J.J. Obrador-Olan, J.F. Juarez, and L. Pastrana-Aponte. 2004. Evaluacion de abono organo-mineral de cachaza en la produccion y calidad de la cana de azucar. Terra. Organo Cientifico de la Sociedad Mexicana de la Ciencia del Suelo. 22:351–357.

Bell, M.J., A.L. Garside, G. Cunningham, N. Halpin, J.E. Berthelsen, and C.L. Richards. 1998. Grain legumes in sugarcane farming systems. Proc. Aust. Soc. Sugar Cane Technol. 20:97–103.

Bokhtiar, S.M., M.A. Gafur, and A.B.M.M. Rahman. 2003. Effects of *Crotalaria* and *Sesbania aculeata* green manures and N fertilizer on soil fertility and the productivity of sugarcane. J. Agric. Sci. 140:305–309.

Bokhtiar, S.M., and K. Sakurai. 2005a. Integrated use of organic manure and chemical fertilizer on growth, yield, and quality of sugarcane in high Ganges river floodplain soils of Bangladesh. Commun. Soil Sci. Plant Anal. 36:1823–1837.

Bokhtiar, S.M., and K. Sakurai. 2005b. Effects of organic manure and chemical fertilizer on soil fertility and productivity of plant and ratoon crops of sugarcane. Arch. Agron. Soil Sci. 51:325–344.

de Resende, A.S., R.P. Xavier, D.M. Quesada, S. Urquiaga, B.J.R. Alves, and R.M. Boddey. 2003. Use of green manures in increasing inputs of biologically fixed nitrogen to sugar cane. Biol. Fertil. Soils 37:215–220.

Environmental Protection Agency. 1994. Microwave assisted acid digestion of sediments, sludges, soils, and oils. EPA Rep. SW-846 Ch 3.2. Method 3051. EPA, Washington, DC.

Environmental Protection Agency. 1996. Method 200.7 Determination of metals and trace elements in water and wastes by inductively coupled plasma-atomic emission spectrometry. Methods for the determination of metals and inorganic chemicals in environmental samples. Noyes Publ., Westwood, NJ.

Garside, A.L., and M.J. Bell. 2001. Fallow legumes in the Australian sugar industry: Review of recent research findings and implications for the sugarcane cropping system. Proc. Aust. Soc. Sugar Cane Technol. 23:230–235.

Garside, A.L., M.J. Bell, G. Cunningham, J. Berthelsen, and N. Halpin. 1999. Rotation and fumigation effects on the growth and yield of sugarcane. Proc. Aust. Soc. Sugar Cane Technol. 21:69–78.

Garside, A.L., and J.E. Berthelsen. 2004. Management of legume biomass to maximise benefits to the following sugarcane crop [CD-ROM]. Proc. Aust. Soc. Sugar Cane Technol. 26.

Garside, A.L., J.E. Berthelsen, and C.L. Richards. 1997. Effect of fallow history on cane and sugar yield of a following plant cane crop. Proc. Aust. Soc. Sugar Cane Technol. 19:80–86.

Garside, A.L., J.E. Berthelsen, B.G. Robotham, and M.J. Bell. 2006. Management of the interface between sugarcane cycles in a permanent bed, controlled traffic farming system. Proc. Aust. Soc. Sugar Cane Technol. 28:118–128.

Glaz, B. 2006. Sugarcane variety census: Florida 2005. Sugar J. 69:12–19.

Glaz, B., S.J. Edme, J.D. Miller, S.B. Milligan, and D.G. Holder. 2002. Sugarcane response to high summer water table in the Everglades. Agron. J. 94:624–629.

Golden, L.E. 1982. Yield and nutrition of sugarcane as influenced by soybeans grown in a soybean-sugarcane rotation. Dep. Agron. Rep. 1982:358–361. Louisiana Agric. Exp. Stn., Baton Rouge.

Jones, J.B., Jr. 2001. Laboratory guide for conducting soil tests and plant analysis. CRC Press, New York.

Kowalenko, C.G. 2001. Assessment of Leco CNS-2000 analyzer for simultaneously measuring total carbon, nitrogen, and sulphur in soil. Commun. Soil Sci. Plant Anal. 32:2065–2078.

Kumar, S., R.S. Malik, and I.S. Dahiya. 1985. Influence of different organic wastes upon water retention, transmission and contact characteristics of a sandy soil. Aust. J. Soil Res. 23:131–136.

Lachat Instruments. 2003. Total nitrogen in Kjeldahl digests of soils and plants. QuickChem method 13–107–06–2-D. Loveland, CO.

Littell, R.C., W.W. Stroup, and R.J. Freund. 2002. SAS for linear models. 4th ed. SAS Institute, Cary, NC.

Moberly, P.K., and J.H. Meyer. 1978. Filter cake: A field and glasshouse evaluation. Proc. S. Afr. Sugar Technol. Assoc. 52:131–136.

Morris, D.R., R.A. Gilbert, C.R. Rainbolt, R.E. Perdomo, G. Powell, B. Eiland, and G. Montes. 2007. Sugarcane yields and soil chemical properties due to mill mud application to a sandy soil. Proc. Int. Soc. Sugar Cane Technol. 26:444-448.

Murphy, J., and J.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta 27:31–36.

Noble, A.D., and A.L. Garside. 2000. Influence of soybean residue management on nitrogen mineralisation and leaching and soil pH in a wet tropical environment. Proc. Aust. Soc. Sugar Cane Technol. 22:139–146.

Obreza, T.A., D.L. Anderson, and D.J. Pitts. 1998. Water and nitrogen management of sugarcane grown on sandy, high-water-table soil. Soil Sci. Soc. Am. J. 62:992–999.

Prasad, M. 1974. The effect of filter press mud on the availability of macro- and micronutrients. Proc. Int. Soc. Sugar Cane Technol. 15:568–575.

Qureshi, M.E., M.K. Wegener, and F.M. Mason. 2000. Mill mud case study in Mackay: An economic study on recycling sugar by-products for the Mackay region. CRC Sugar Occasional Publ., Townsville, Australia.

Rice, R.W., R.A. Gilbert, and R.S. Lentini. 2006. Nutritional requirements for Florida sugarcane. Univ. of Florida Electronic Data Information Source (EDIS) Database, http://edis.ifas.ufl.edu/SC028. [verified 4 Mar. 2008].

Roth, G. 1971. The effects of filter cake on soil fertility and yield of sugarcane. Proc. S. Afr. Technol. Assoc. 45:142–148.

Samuels, G., and P. Landrau. 1956. Filter-press cake as a fertilizer. Proc. Int. Soc. Sugar Cane Technol. 9:119–131.

Wiedenfeld, R.P. 1998. Previous-crop effects on sugarcane responses to nitrogen fertilization. Agron. J. 90:161–165.

Wilhelm, W.W., K. Ruwe, and M.R. Schlemmer. 2000. Comparison of three leaf area index meters in a corn canopy. Crop Sci. 40:1179–1183.

Yadav, R.L. 1995. Soil organic matter and NPK status as influenced by integrated use of green manure, crop residues, cane trash and urea in sugarcane-based crop sequences. Bioresour. Technol. 54:93–98.

Yadav, R.L., and R.P. Verma. 1995. Crop residue management to conserve soil organic matter content in sugarcane-based crop rotations. Bioresour. Technol. 51:241–245.

Yaduvanshi, N.P.S., and D.V. Yadav. 1990. Effects of sulphitation press mud and nitrogen fertilizer on biomass, nitrogen economy and plant composition in sugarcane and on soil chemical properties. J. Agric. Sci. 114:259–263.